To: Vought-Sikorsky Aircraft Division, United Aircraft Corp.
Att: Mr. Charles J. McCarthy, General Manager



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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



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ADVANCE CONFIDENTIAL REPORT #245

# A PROFILE-DRAG INVESTIGATION IN FLIGHT ON AN EXPERIMENTAL FIGHTER-TYPE AIRPLANE - THE NORTH AMERICAN XP-51

(Air Corps Serial No. 41-38)

By John A. Zalovcik

Langley Memorial Aeronautical Laboratory
Langley Field, Va.



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# A PROFILE-DRAG INVESTIGATION IN FLIGHT ON AN EXPERIMENTAL FIGHTER-TYPE AIRPLANE - THE NORTH AMERICAN XP-51

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## SUMMARY

A profile-drag investigation has been conducted in flight by the National Advisory Committee for Aeronautics, Langley Field, Va., on an experimental fighter-type airplane, the North American XP-51 (Air Corps Serial No. 41-38), at the request of the Army Air Corps. This airplane, which was provided for the tests by the Materiel Division of the Army Air Corps, is equipped with wings that incorporate airfoil sections designed to include to a moderate degree the design principles of the NACA low-drag airfoil sections. Wake-survey measurements were made behind a right-wing section with an aileron at about 16 inches outboard of the inboard end of the aileron. This wing section had a chord of about 66.25 inches and a maximum thickness of about 13.5 percent at 40-percent chord.

Profile-drag tests were made on various surface conditions for which the following results were obtained:

(a) At an airplane lift coefficient of about 0.15 corresponding to a maximum speed in level flight, a Reynolds number of about 14,000,000, and a Mach number of about 0.5, the profile-drag coefficient was (1) 0.0070 for the unfinished surface, (2) 0.0063 for a factory finish, (3) 0.0059 for the factory finish modified by sanding the edges of painted insignia, and (4) 0.0053 for a smoothened and faired surface obtained by filling and sanding.

(b) A minimum value of profile-drag coefficient of 0.0052 was realized with the smoothened and faired surface and this at a Reynolds number

of about 16,000,000 and a lift coefficient of about 0.10 which corresponds to a shallow dive at an indicated airspeed of 340 miles per hour.

## INTRODUCTION

Over the past several years a series of low-drag airfoils has been designed by the NACA to take advantage of the low drag afforded by extensive laminar boundary layers. This was accomplished, in general, by moving the point of minimum pressure to about 60 or 70 percent of the chord. Tests of these airfoils in wind tunnels and in flight have shown that profile-drag coefficients of about one-half of those of conventional airfoils may be obtained. The majority of these tests, however, were conducted on airfoil models with surfaces made aerodynamically smooth and there is still largely to be determined how much of the reduction in profile-drag coefficient indicated by the tunnel tests may be realized on factory-constructed airplane wings incorporating such airfoil sections.

There are at the present a number of airplanes which have wings designed on the basis of the new low-drag principles. The one used in the present investigation was provided by the Materiel Division, Army Air Corps, and has a compromise low-drag airfoil section with the minimum pressure point only at 40-percent chord instead of 60 or 70 percent which is characteristic of the NACA low-drag airfoil sections. With the minimum pressure point this far forward, it would be expected that the profile drag could not be as low as that obtainable with the best low-drag sections.

## APPARATUS AND TESTS

The airplane with which the tests were made is a low-wing, single-engine monoplane. (See fig. 1.) It has a gross weight of about 7800 pounds, a wing span of about 37 feet, and a wing area of about 236 square feet.

Wake surveys were made by means of a rake shown in figure 2 mounted behind a wing section located at about 16 inches outboard of the inboard end of the aileron. (See fig. 3.) This wing section had a chord of about 66.25 inches and a maximum thickness of about 13.5 percent at 40-percent chord. The ordinates of the test section measured relative to an arbitrarily chosen chord are given in table I.

Profile-drag tests have been conducted on the following surface conditions of the wing section:

(1) Unfinished

(2) Factory finished

(3) Factory finished and modified by sanding the insignia

(4) Smoothened and faired by filling and sanding

(5) Condition (d) with protuberances attached to fix transition

In the unfinished condition the test section was relatively free from large surface irregularities. It did, however, have insignia painted on the upper and lower surfaces (see fig. 3) and a general unfairness of surface as shown in figure 4 which presents an index of surface waviness as measured with a curvature gage shown in figure 5. The leading edge of the insignia in the plane of the surveys was located at about 20-percent chord on the upper and lower surfaces and had a built-up edge of about 0.005 inch. The lower surface had a large ridge about 0.02 inch high resulting from a poor skin joint and extending over a large portion of the span.

The factory finish was applied to the wing surfaces by the manufacturer's representative who used the following procedure. The painted insignia on the wing were first sanded and a coat of primer applied to the wing surfaces. This was then followed with an application of two or three coats of filler, a filling of seams with spot putty, and a general sanding. Another coat of filler was next applied and sanded. This was followed with a coat of aluminum paint and the painting of insignia. The final finish was given by spraying on two coats of clear lacquer and sanding lightly.

With the factory-finished surface, the test section still had nearly the same surface irregularities (see fig. 4) as the unfinished surface. Some improvement of the surface condition, however, was obtained in the fairing of seams and rivets. Further improvement in this surface condition was obtained with the fairing of the insignia edges by sanding.

The best surface condition tested was that with local surface waves and irregularities smoothened and faired. This improved surface condition shown in figure 4 was obtained by applying eight coats of filler by means of a knife to a thickness of about 0.030 inch and then sanding, using long sanding strokes parallel to the chord. This then was followed by local filling and sanding to remove surface waves. Finally, two coats of aluminum paint and two coats of clear lacquer were applied and sanded lightly. These latter coats of paint and lacquer were applied only to allow the test section to blend in with the color scheme of the remainder of the wing.

In order that some information may be obtained as to the effect of fixed transition on the profile-drag coefficient of the final improved surface, two tests were made with strips of tape 0.018 inch thick and about 3 feet long attached to the upper and lower surfaces. In one test the backward movement of transition was limited to 15-percent chord on the upper and lower surfaces and in the other to 30-percent chord.

All of the tests were made at a pressure altitude of 10,000 feet and covered a range of indicated airspeeds from about 190 to 340 miles per hour, the latter speeds being obtained in shallow dives. This range of speeds corresponded to a range of airplane lift coefficients from about 0.36 to 0.11, Reynolds numbers from about 9,000,000 to 16,000,000, and Mach numbers from about 0.3 to 0.5. In order that comparable flight conditions would be maintained for each of the test flights with different surface conditions of the test section, the airplane was trimmed for each speed run and thus approximately the same aileron positions were kept throughout the series of tests.

## RESULTS AND DISCUSSION

Results of the investigation are given in figures 6 and 7. In figure 6 the results are presented for successively improved surface conditions. At a lift coefficient of 0.15, corresponding to a maximum speed in level flight, the profile-drag coefficient of the unfinished test section was 0.0070. On applying the factory finish to the wing the profile-drag coefficient was reduced by about 0.0007, or 10 percent. In this case transition on the upper surface may have been limited to the forward edge of the insignia which were located in the plane of the measurements.

Upon sanding the edges of the insignia a further decrease of about 0.0004 in the profile-drag coefficient was realized. A final reduction of the profile-drag coefficient of about 0.0006 was obtained when the local surface waves and other irregularities were smoothened and faired, thus giving a profile-drag coefficient of about 0.0053. A large portion of the latter reduction was probably due to the improvement of the lower surface condition at the forward ridge (12-percent chord) produced by the butt joint. The improvement in surface condition from that represented by the unfinished test section to that with local surface waves and irregularities smoothened and faired resulted in a reduction of profile-drag coefficient on the order of 25 percent of that of the unfinished panel. The minimum profile-drag coefficient obtained was slightly less than that given above for the maximum speed, level flight condition, the value being 0.0052 at a lift coefficient of about 0.10 and a Reynolds number of about 16,000,000.

It is estimated that the over-all drag reduction resulting from application of the factory finish to the wing would increase the maximum speed of the airplane by roughly 4 miles per hour. If the improvements to the unfinished wing surface suggested in figure 3 were made, it is estimated that the speed of the airplane may be increased by at least 8 miles per hour. It is further suggested that all removable surface panels which cannot be faired by applying filler be made as flush with the remainder of the surface as is possible. In the case of the present airplane, it is estimated that the profile drag of the section on the right wing with ammunition and gun doors is increased on the order of 15 percent by the leading edges of these doors.

In figure 7 the results are given for tests with transition artificially produced. The drag of the strips used to limit the backward movement of transition has been estimated on the basis of the results of reference 1 and subtracted from the results obtained, since it would be meaningless to present the results in any other form. The increases in profile-drag coefficient shown in figure 7 therefore represent the increased skin friction due to premature transition.

During one of the recorded test runs (in the middle of the speed range) on the test section with transition limited to 15-percent chord on the upper and lower surfaces, the strip fixing transition on the lower surface came off, so that information at that particular speed was obtained

with transition limited to 15-percent chord on the upper and lower surfaces and to 15-percent chord on the upper surface alone. The data so obtained were roughly extrapolated (shown dotted in fig. 7) for the remainder of the test flight conditions by assuming a constant difference in profile-drag coefficient of the test section with transition limited to 15-percent chord of the upper and lower surfaces and to 15-percent chord on the upper surface alone.

With the backward movement of the transition point on the upper and lower surfaces of the smooth wing limited to 30-percent chord, the profile-drag coefficient at a lift coefficient of 0.15, corresponding to maximum speed in level flight, was increased by about 6 percent; with transition limited to 15 percent chord on the upper surface alone, the profile-drag increase amounted to 16 percent; with transition limited to 15-percent chord on the upper and lower surfaces, an increase of profile-drag coefficient of about 33 percent is indicated on the basis of extrapolation. These results indicate that transition on the upper surface of the smooth wing must be occurring beyond 30-percent chord since the profile-drag coefficient is still affected by fixing transition at 30-percent chord.

## CONCLUSIONS

The profile-drag tests on the compromise low-drag wing lead to the following conclusions:

1. At an airplane lift coefficient of about 0.15 corresponding to maximum speed in level flight, a Reynolds number of about 14,000,000, and a Mach number of about 0.5 the profile-drag coefficients obtained may be summarized as follows:

| Condition of surface | Profile-drag coefficient |
|---|---|
| (1) Unfinished | 0.0070 |
| (2) Factory finished | 0.0063 |
| (3) Factory finished and modified by sanding insignia | 0.0059 |
| (4) Smoothened and faired by filling and sanding | 0.0053 |

2. A minimum profile-drag coefficient of about 0.0052 was realized with the final smoothened and faired surface and this at a Reynolds number of about 16,000,000 and a lift coefficient of about 0.10 which corresponds to a shallow dive at an indicated airspeed of about 340 miles per hour.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

## REFERENCE

1. Jacobs, Eastman N.: Airfoil Section Characteristics as Affected by Protuberances. Rep. No. 446, NACA, 1932.

TABLE I. - ORDINATES OF WING SECTION TESTED (XP-51)

| $\frac{x}{c}$ | $\frac{y_U}{c}$ | $\frac{y_L}{c}$ |
|---|---|---|
| 0 | 0 | 0 |
| .0125 | .0184 | -.0134 |
| .025 | .0267 | -.0181 |
| .050 | .0368 | -.0249 |
| .075 | .0438 | -.0304 |
| .10 | .0500 | -.0349 |
| .15 | .0598 | -.0412 |
| .20 | .0664 | -.0464 |
| .25 | .0717 | -.0506 |
| .30 | .0763 | -.0546 |
| .35 | .0787 | -.0550 |
| .40 | .0793 | -.0552 |
| .45 | .0790 | -.0545 |
| .50 | .0769 | -.0530 |
| .60 | .0675 | -.0447 |
| .70 | .0520 | -.0319 |
| .80 | .0338 | -.0168 |
| .90 | .0133 | -.0066 |
| .998 | .0011 | -.0011 |
| 1.000 | 0 | 0 |

Ordinates beyond $\frac{x}{c}$ =0.80 were measured with inboard trailing edge of aileron in line with trailing edge of flap.

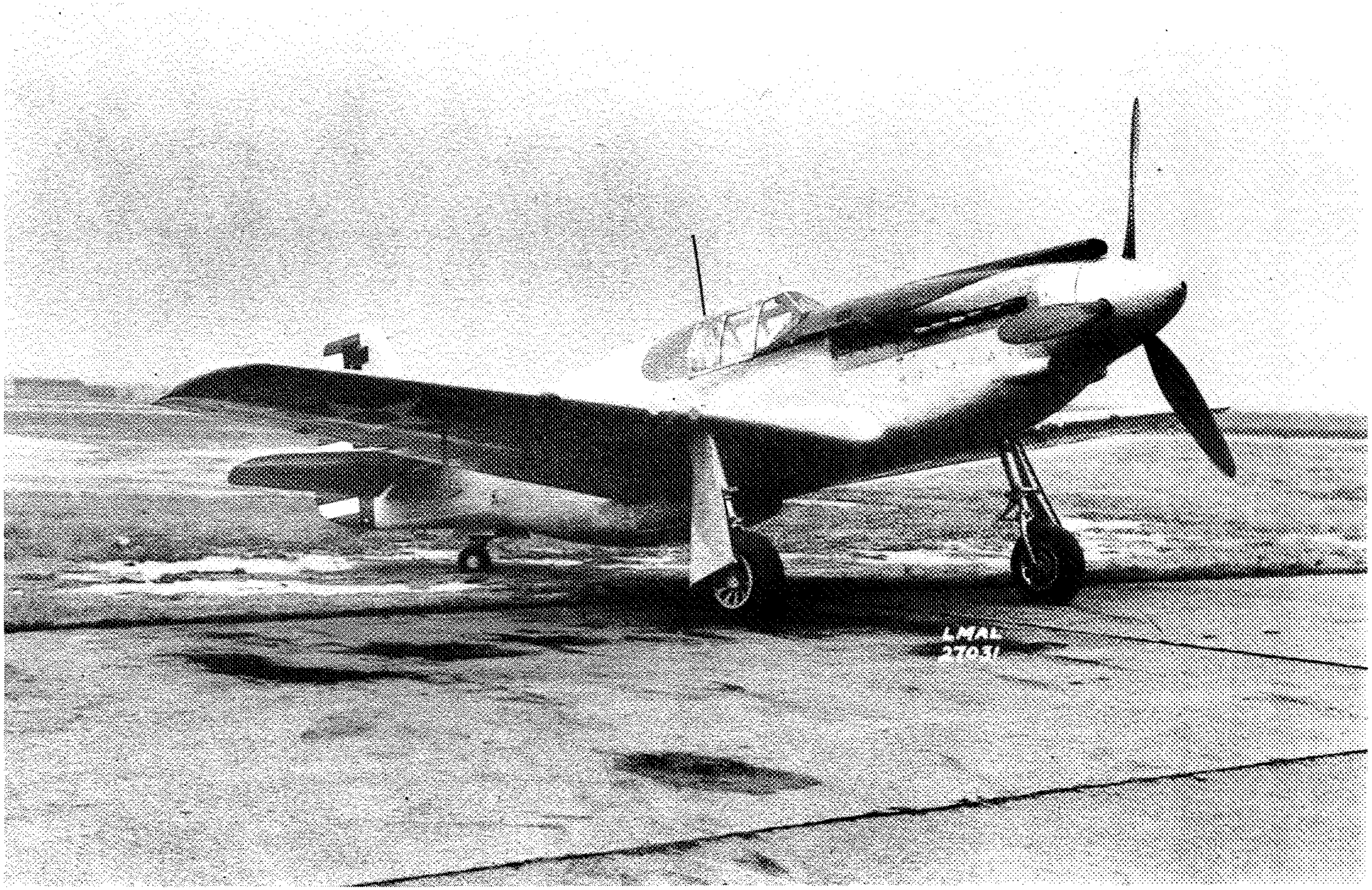



Figure 1.- Experimental fighter-type airplane tested (XP-51).

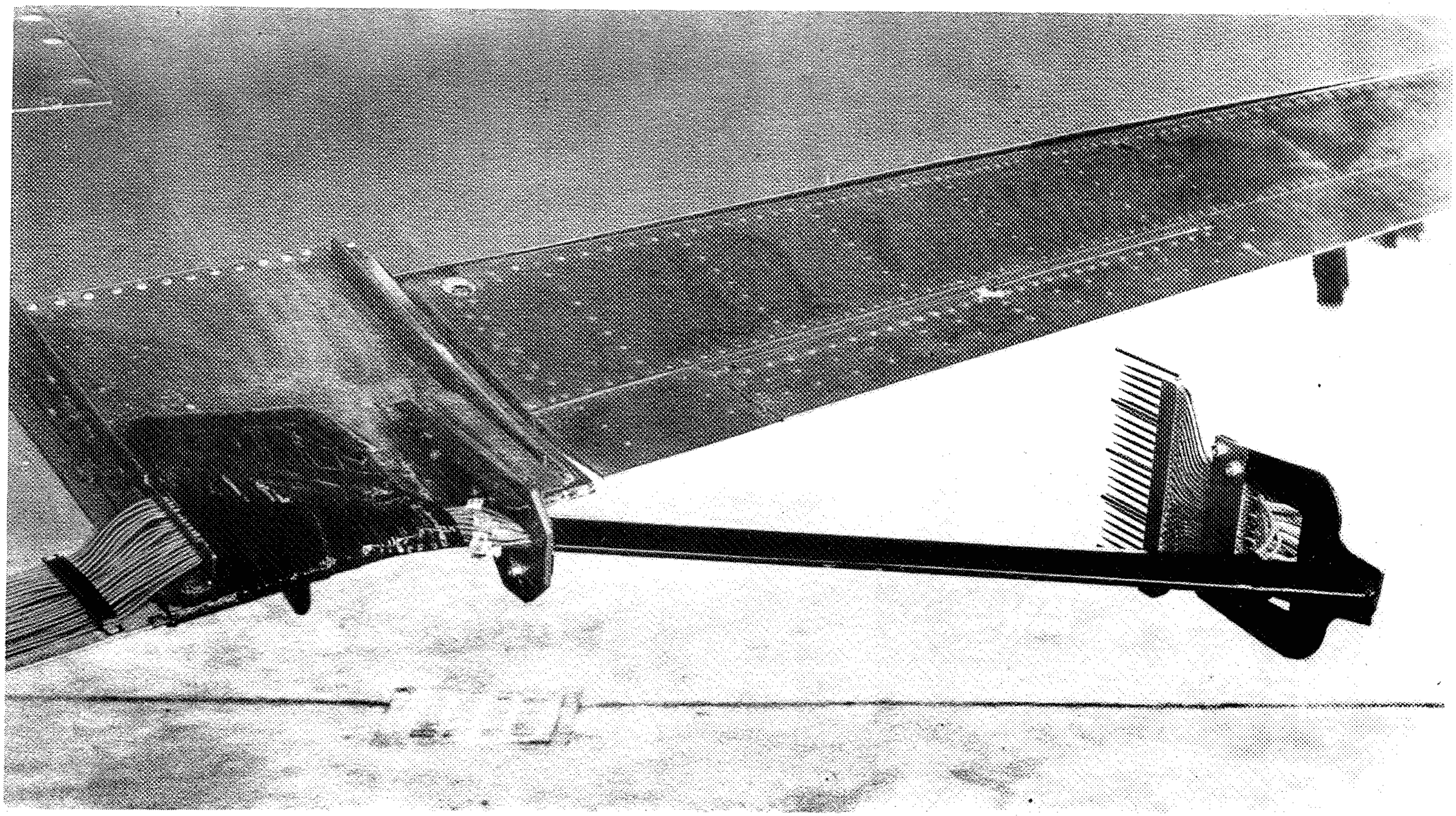
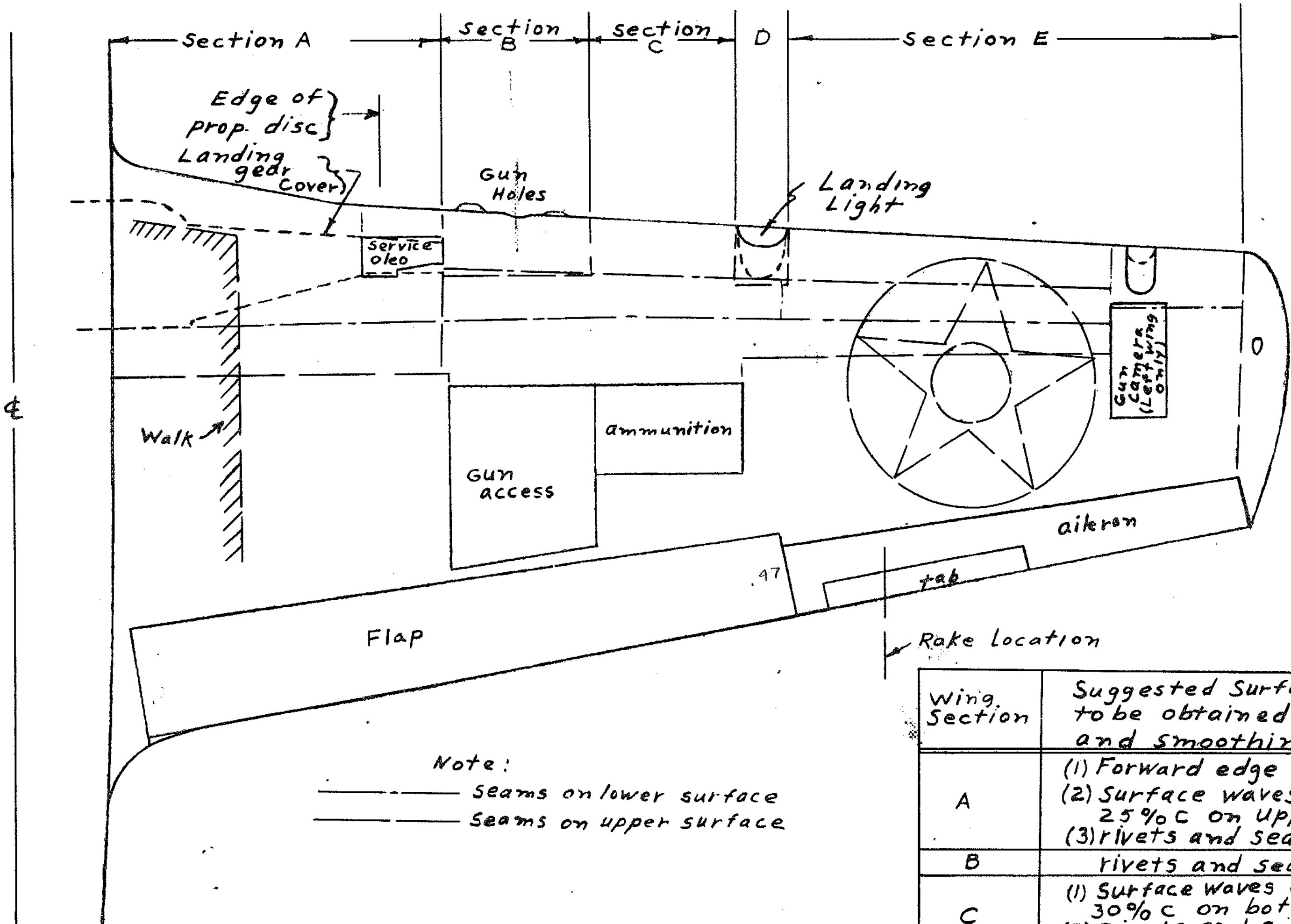


Figure 2.- Survey rake mounted behind test section of airplane wing (XP-51).




| Wing Section | Suggested Surface Improvements to be obtained by Fairing and Smoothing |
|---|---|
| A | (1) Forward edge of painted walk<br>(2) Surface waves over forward 25% c on upper surface<br>(3) rivets and seams completely |
| B | rivets and seams completely |
| C | (1) Surface waves over forward 30% c on both surfaces<br>(2) Rivets and seams completely |
| D | Landing light cover |
| | (1) Edges of Insignia<br>(2) Surface waves over forward 40% c on both surfaces<br>(3) Rivets and seams completely |

Figure 3 Sketch showing wing surface details (XP-51)

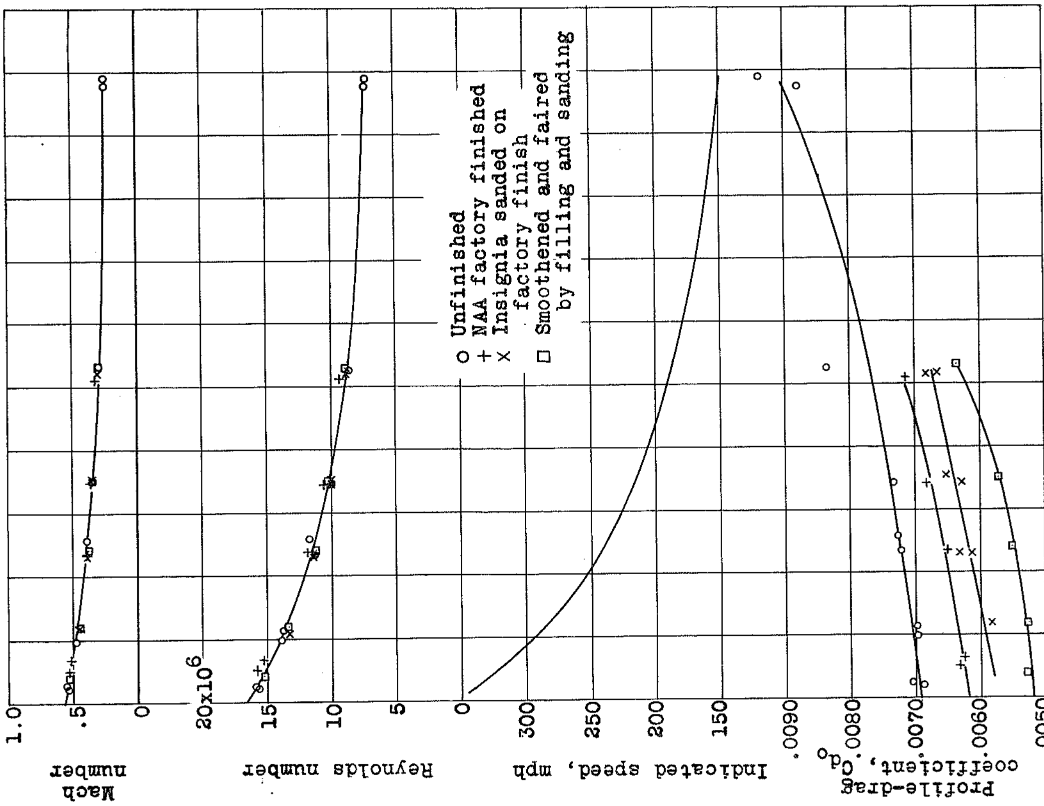



Figure 6.- Profile-drag coefficient for successively improved surface conditions of test section (XP-51).

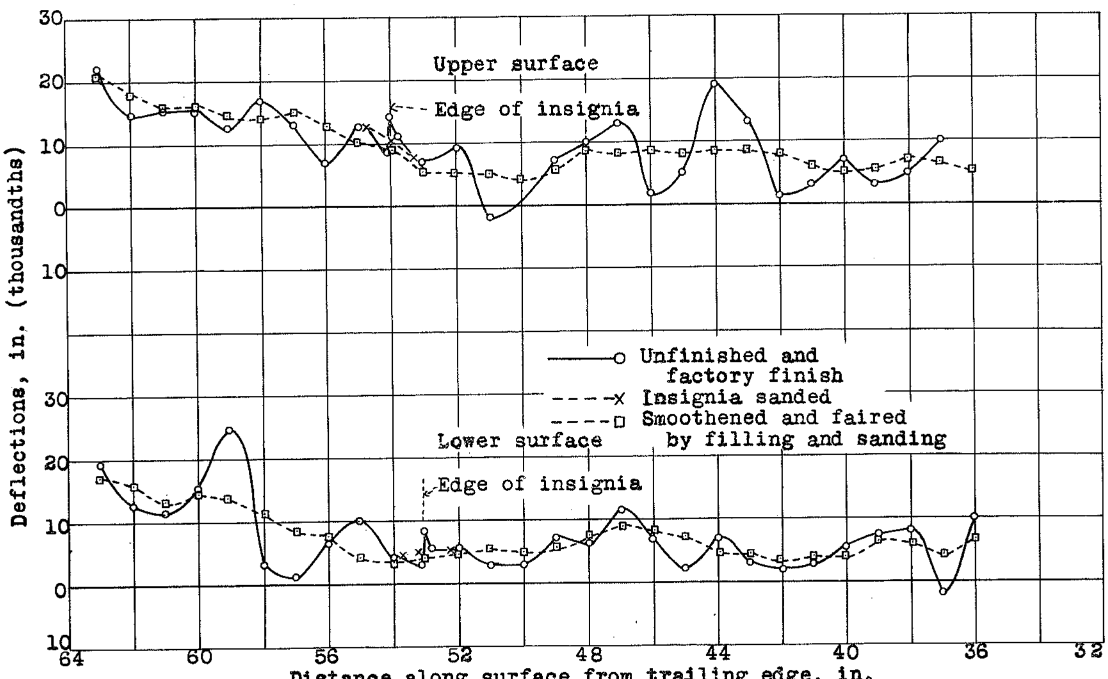



Figure 4.- Surface waviness measurements at test section (XP-51).

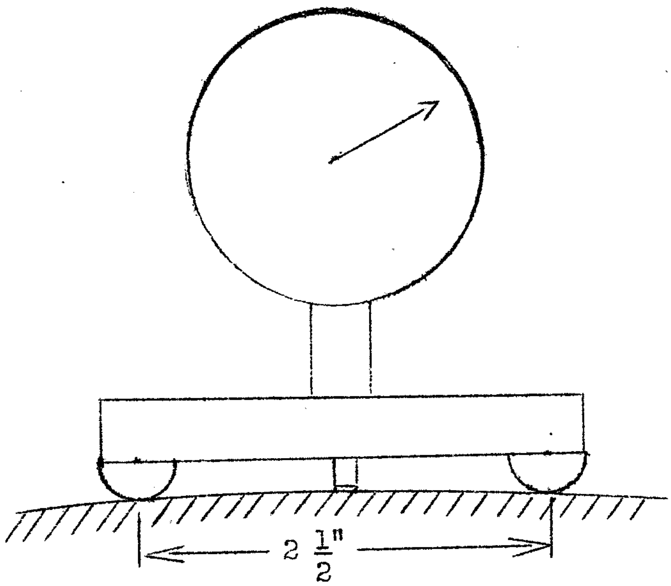



Figure 5.- Sketch showing surface curvature gauge used to measure surface waviness (XP - 51).

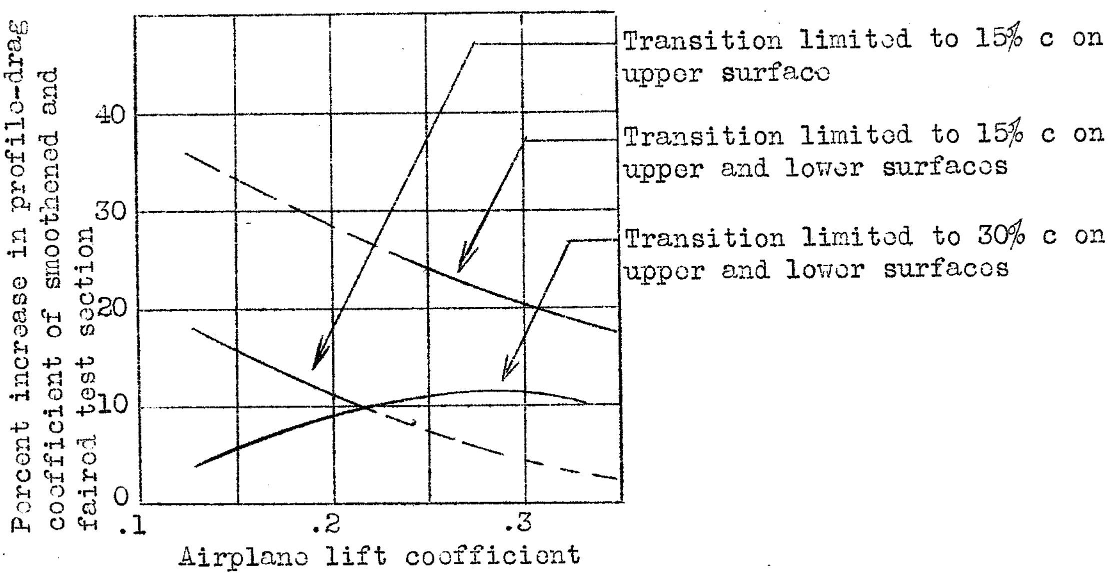



Figure 7.- Profile drag results on smoothened and faired test section with fixed transition (XP - 51).